FISHERIES RENTS: THEORETICAL BASIS AND AN EXAMPLE

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ABSTRACT

The concept of natural resource rents is much used in the natural resource and fisheries economics literature. It is therefore somewhat surprising that in this same literature it is difficult to find a clear definition of either natural resource rents or fisheries rents. Possibly, as a result, the concept is often loosely employed and in some texts it appears to be taken to be virtually synonymous with profits.

This paper begins by attempting to provide a definition of the concept of natural resource rents in general and fisheries rents in particular that is both unambiguous and in conformance with the more traditional concept of economic rents as originally proposed by D. Ricardo in the early 19th century. On this basis, the paper goes on to elucidate the properties of the fisheries rents function and how it depends on the rate of harvesting, stock level and, indeed, fisheries management.

With the theory clarified, the paper discusses the practicalities of estimating resource rents on the basis of empirical data and what steps need to be taken in order to obtain such estimates. The estimation of rent loss, since it unavoidably compares actual rents with potential ones both of which typically evolve over time, poses a different set of problems. These are discussed in the paper and options suggested. Finally, mainly for illustrative purposes, the global ocean fishery is used as an example of the estimation of rent loss in fisheries.

Keywords: Economic rents, fisheries rents, rent loss, fisheries rents loss

INTRODUCTION

The concept of economic rents has a long history in economic theory. A. Smith used it in his value theory as one component of profits (see Smith 1776). D. Ricardo (1817) further developed the concept and applied it in his theory of diminishing returns to agriculture. Hence the well known concept of land rents. Later classical economists including J.S. Mill and K. Marx employed the concept in similar ways (see e.g. Samuels et al. 2003). Following the tradition in the field I will often refer to rents in this classical sense as Ricardian rents.

The label natural resource rents, is much used in the natural resource economics literature in various contexts. These include the contribution of natural resource rents to economic growth (see e.g. Sachs and Warner 1991 and the references therein), the amount of rents as a measure of economic efficiency (see e.g. Homans and Wilen 2003), rents as a source of inequality (see e.g. Samuelson 1974), rents as a subject for taxation (see e.g. Grafton 1996) and so on. In spite of this widespread use of the term, it is difficult to find a clear definition of either natural resource rents or fisheries rents in the literature. What most authors seem to have in mind is some variant of the Ricardian land rents discussed above. However, the concept is often loosely employed and in some texts appears to be virtually synonymous with profits.

In his textbook on fisheries economics by one of the most prominent fisheries economist of our time, Lee Anderson (1977), there are, according to the index, seven page references to the concept but no definition. On the other hand in the textbook on mathematical bioeconomics by Colin Clark (1976) there is no use of the term. In the textbook by Cunningham, Dunn and Witmarsh (1985) there are 24 page references to the concept but again no definition. In the influential volume Rights Based Fishing by Neher et al, there are eight references to the term but, once again, no definition. In Hannesson's textbook of 1993, there are 40 page references to the term. Unlike the previous authors, Hannesson offers what amounts to a definition of the term (p.10). More precisely, he identifies the concept with the price an owner of the fishery could extract from the users. This is in accordance with the classical use of the term discussed above. However, Hannesson goes on to assert that this would be equal to the profits the buyers could gain from using the resource (p.10). By this Hanneson seems to align himself with a common view in the fisheries economics literature that rents are identical to profits. This, however, would only be true in very special cases as explained in this paper.

The remainder of the paper is organized as follows: In section 1 the general concept of economic rents is defined and explained. The paper then goes on to consider fisheries rents specifically and discusses its properties. In the following section the relationship between rents and profits is discussed. The final section of the paper applies the theory in a simple manner to estimate global fisheries rent loss based on a stylized description of the global fishery.

ECONOMIC RENTS

The concept of economic rents is reviewed by Armen Alchian in the New Palgrave Dictionary of Economics (1987). According to him, economic rents are:

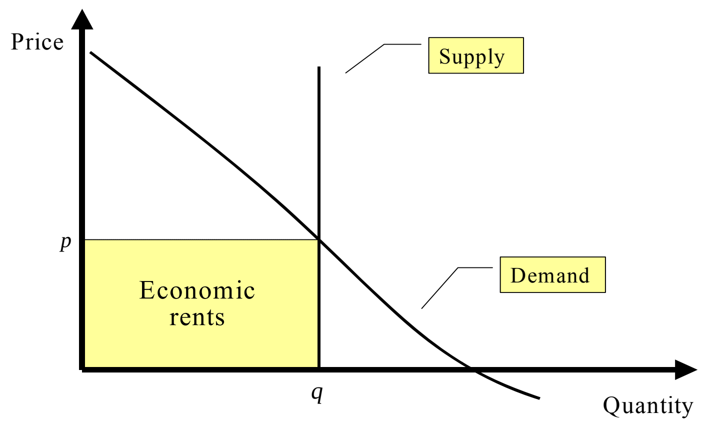
"the payment (imputed or otherwise) to a factor in fixed supply".

This definition is formulated in terms of a factor of production. However, quite clearly, is can be extended to cover any restricted variable including output in the profit function. An extended definition in same spirit would read:

"the payment (imputed or otherwise) to a variable in fixed quantity".

Alchian illustrates this definition with the familiar diagram in Figure 1 often used to illustrate Ricardo's theory of land rents. In this diagram, there is a demand curve and a supply curve. The market-clearing price is *p*. However, since the quantity of the factor is assumed fixed, the corresponding supply, *q*, would be forthcoming even if the price were

Figure 1
Economic Rents



zero. Hence, the entire price, p, may be regarded as a surplus per unit of quantity. The total surplus or economic rent attributable to the limited factor is the rectangle $p \cdot q$.

Note that as far as the concept of economic rents is concerned it is immaterial why or how the supply is fixed. It may be fixed because of limited natural resource availability as Ricardo's land of high quality, or it may be fixed for economic reasons by suppliers enjoying some monopolistic position. In the latter situation the rents are sometimes referred to as monopoly rents (Varian 1984). What is crucial for the existence of economic rents is that the marginal cost of supplying the quantity is less than the demand price at that quantity. The difference constitutes rents per unit of quantity. If, as in Figure 1 and Ricardo's theory of land rents, the marginal cost of supply is actually zero, the rent per unit of quantity is the demand price.

It is important to realize that the economic rents depicted in Figure 1 also represent profits[1] to the owner of the factor in fixed supply. It doesn't, however, represent the total economic benefits of the supply q. This is measured by the sum of economic rents and the demanders' surplus represented by the upper triangle in the diagram. Thus, if the demanders are producers, their profits would be the demanders' surplus. Total profits from the supply q, would be sum of economic rents and the demanders' surplus. Thus, in this case, profits would be greater than economic rents. Some authors refer to the demanders' surplus in Figure 1 as intra-marginal rents (see e.g. Coglan and Pascoe 1999 for fisheries and Blaug 2000 more generally).

For later purposes it is useful to note that economic rents can also be written as $D(q) \cdot q$, where $D(q)$ represents the value of the demand function at q. It is well known (see e.g. Varian 1984) that in competitive markets if the factor is used for production purposes $D(q)$ represents the marginal profits of using the factor. When, on the other hand, the factor is used directly for consumption $D(q)$ would be proportional to the marginal utility of consuming the factor.

The concept of economic rents as defined above presupposes a factor in fixed supply. Obviously, the empirical relevance of factors in fixed supply may be questioned. After all it is in the nature of the economic activity to find ways to adjust supply to demand, particularly when profits can be made doing it. Even, Ricardo's (1817) argument in terms of the "original and indestructible powers of the soil" does not ring true. Surely, modern technology has enabled us to both reduce and enhance these powers. Thus, it turns out to not to be easy to find examples of factors of production that are truly in fixed supply especially in the long run. Indeed, the most likely candidates for such factors seem to be natural resources which cannot be augmented. Unique natural geological phenomena seem to belong to that category. In the very short run, on the other hand, many factors are in fixed supply and, consequently capable of earning economic rents. To represent this phenomenon of transient or temporary economic rents, Marshall (according to Achian 1987) apparently initiated the concept of quasi-rents.

If there is no fixed factor, economic rents in the traditional (Alchian 1987) sense are not really defined. However, as we have seen, what is crucial for the existence of a surplus or rents is not fixed supply (i.e, that the marginal cost of supply jumps from zero to infinity at some given quantity) but that the marginal cost of supply be less than the demand price. This observation motivates the following generalized definition of economic rents which includes Alchian's definition of rents, and hence Ricardo's land rents, as well as monopoly rents as special cases.

> "Economic rents are payments (imputed or otherwise) to a variable above the marginal costs of supplying that variable."

Adopting this definition, denote the quantity of the factor by q. Let other relevant variables (such as other prices, natural resources stocks, expectations and so on) be represented by the vector $\mathbf{z}$. Then we can write the (inverse) demand function for the factor as:

$$p=D(q,\mathbf{z}),$$

Without loss of generality let the marginal cost of supplying the variable be zero (Alchian's definition of rents). Given this, an expression for rents is:

$$R(q,\mathbf{z})=D(q,\mathbf{z})\cdot q\ .$$

Of course the production process may involve more than one independent varaible. The above expression for economic rents generalizes to the case of many variables in a straight-forward manner. Let $\Pi(\boldsymbol{q},\boldsymbol{z})$ be the profit function with the quantity (inputs and outputs) vector $\boldsymbol{q}$. Then rents from all these variables are defined as:

$$R(\boldsymbol{q},\boldsymbol{z})=\Pi_{\boldsymbol{q}}(\boldsymbol{q},\boldsymbol{z})\cdot\boldsymbol{q}\equiv\sum_{i=1}^{I}\Pi_{q_i}(\boldsymbol{q},\boldsymbol{z})\cdot q_i$$

Note that when there are more then one variables in the objective function, economic rents from each of them depends in general on the amount of all the others.

FISHERIES RENTS

Consider a fishing industry characterized by the instantaneous profit function:

(1) $\Pi(q,x)$, defined for $q,x\geq 0$,

where q denotes the volume of harvest and x the stock of the resource both at time t. The profit function is taken to have the usual properties. More precisely: $\Pi(0,x)=\Pi(q,0)\leq 0$, $\Pi_x(q,x)>0$ and $\Pi_q(q,x)>0$ for $q< q°>0$. For analytical convenience it is, moreover, assumed that the profit function is differentiable as needed. In what follows, we will normally refer to $\Pi(q,x)$ as applying to the industry as a whole. In that case $\Pi(q,x)$ must be some aggregate of individual profit functions.

The resource evolves according to the differential equation:

(2) $\dot{x}=G(x)-q$, defined for $x\geq 0$,

where $G(x)$ is the renewal function of the natural resource having the usual properties (Clark 1976). As the $\Pi(q,x)$ function, the function $G(x)$ is assumed to be as differentiable as needed.

Optimal harvesting

To understand the nature of fisheries rents it is convenient to consider first optimal or profit maximizing behaviour. All the key results concerning fisheries rents in the case of optimal harvesting carry over to suboptimal harvesting

The firms in the industry, and, consequently, the industry as a whole, are assumed to seek to maximize the present value of profits. For this purpose they can decide to be active and, if active, select the path of extraction, $\{q\}$. Formally this problem can be expressed as:

(I) $\underset{\{q\}}{Maximize}\ V = \int_0^{\infty} \Pi(q,x) \cdot e^{-r \cdot t} dt$,

$$\text{Subject to: } \dot{x} = G(x) - q$$
$$x(0) = x_0$$
$$x, q \geq 0.$$

According to the maximum principle (Pontryagin et al. 1962, Leonard and Long 1992). The necessary (and in this case sufficient) conditions for solving problem (I) include:

(3.1) $\Pi_q - \lambda \leq 0$, $q \geq 0$, $(\Pi_q - \lambda) \cdot q = 0$,

(3.2) $\dot{\lambda} - r \cdot \lambda = -\Pi_x - \lambda \cdot G_x$,

(3.3) $\dot{x} = G(x) - q$,

(3.4) Appropriate transversality conditions (for infinite time).

Expressions (3.1)-(3.4) describe the behaviour of a profit maximizing fish resource extraction industry. If the industry (or rather individual firms in the industry) takes prices as exogenous and these prices are "true" as is usually assumed, conditions (3.1)-(3.4) also represent a social optimum.

Now, as discussed in the previous section, economic rents are defined as $D(q) \cdot q$, where $D(q)$ represents the demand for the factor in fixed supply. In the context of fisheries and, indeed, other natural resource extraction, the demand is the derived demand for the natural resource, i.e. $D(q) = \Pi_q(q,x)$. Hence, adopting Alchian's definition of economic rents, resource rents are defined as

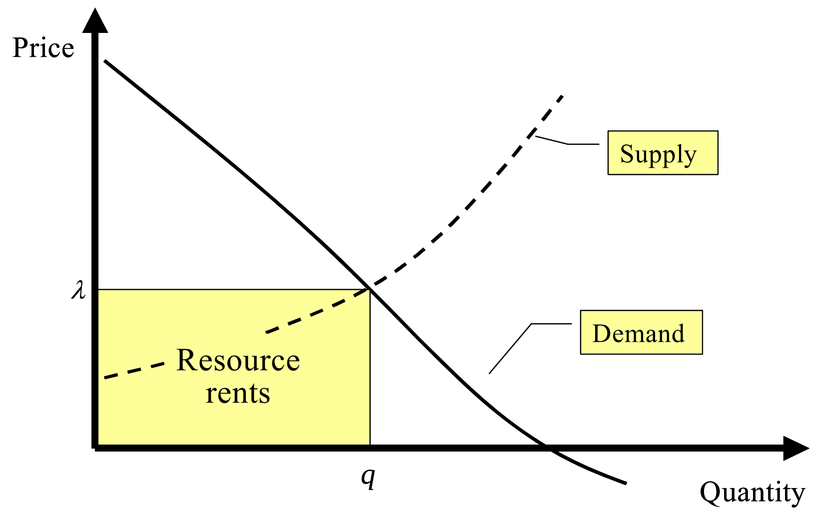
(4) $R(q,x) = \Pi_q(q,x) \cdot q$

Note that these are instantaneous rents. They refer to a point in time. Resource rents for the harvesting programme as a whole would be given by the present value of the complete time path of rents.

In the fishing industry defined above, the supply price of harvest at quantity q is given by the co-state variable, λ. This is a function basically defined by conditions (3.2)-(3.4) above. This function depends in general on the state of the resource, x, and the level of extraction, q as well as exogenous variables such as prices. The demand for harvest, however, is given by condition (3.1). The demand price (i.e. λ) depends also on the state of the resource the level of extraction, q as well as exogenous variables. Thus, if the optimal extraction at a point of time is positive, there exists a supply/demand equilibrium defined by conditions (3.1) to (3.4). It follows that for the fishery we may draw a resource rent diagram corresponding to the conventional one in Figure 1.

As the supply curve of q is drawn in Figure 2, the area referred to as "Resource rents" does not appear to be economic rents at all, although parts of it may represent a producer's surplus (in this case resource owner's surplus). Note, however, that λ is merely an imputed or notional price. It represents the opportunity cost of reducing the size of the resource, sometimes referred to as a user cost (Scott 1955). This user cost is the result of the maximization of the present value of profits and is generated by the concern that "oversupply" now might hurt future profits. Thus, it is similar to the user costs a monopolist might calculate for his own current supply. The difference is that in the natural resource context, the imputed user costs stem from the scarcity of the resource. In the traditional monopolist situation it comes from the perceived

Figure 2
A Resource Extraction Industry: Resource Rents



downward slope of the demand curve – scarcity of demand. In any case, the resource user cost does not represent outlays of money. Thus, in a certain sense it is not marginal cost at all. It is certainly not a marginal cost in the sense of Ricardo and the definition of economic rents discussed in the previous section.

We conclude that the multiple $\lambda \cdot q$ appears to represent economic rents in the traditional (Ricardian and Marshallian) sense as defined by Alchian above. In any case, this multiple seems the closest parallel to economic rents that can be found in the fishery or for that matter any resource extraction industry.

An important message of equation (4) is that resource rents are a function of both the extraction rate and the level of the resource as well as of other variables entering but not explicit in the profit function. We refer to this as result 1.

Result 1
Fisheries rents depend in general on extraction rates, the level of the resource and the exogenous variables of the situation including prices.

Given that some level of harvest is profitable (i.e. the optimal action is not to select q=0) resource rents are nonnegative. We refer to this result as result 2.

Result 2
Assuming that harvesting is profitable, resources rents in the fishing industry defined by (1) and (2) are nonnegative.

Proof:

If extraction is profitable, the optimal extraction is $q^*>0$. Therefore, $\Pi_q(q^*,x)=\lambda$ according to (3.1). It is well known (see e.g. Leonard and Long 1992) that along the optimal path, the shadow value of the resource, $\lambda^*=\partial V^*/\partial x$, where V^* refers to the optimal value of the programme. If extraction is profitable $\partial V^*/\partial x$ cannot be negative. It follows that $R(q^*,x) = \Pi_q(q^*,x)\cdot q^* = \lambda^* \cdot q^* \geq 0$.

Non-optimal harvesting

The above theory of rents applies equally to non-optimal as to optimal harvesting. This is easily seen by noting that for any given level of resource, *x*, rents according to (4) will be defined by the harvest level, i.e., *q*, irrespective of how that may be determined.

It is informative to explore this a bit more formally. Consider for instance a fishing industry whose firms maximize current profits. For concreteness this can be imagined to be an open access fishery. Now, let an upper bound on the harvest $q°$ be imposed. This can be seen as a fisheries management device. By altering this upper bound, the harvest can be made to cover any range from zero to the open access harvest level. Since this range includes the profit maximizing harvest level (for any existing biomass), the optimal fishery is included in this formulation as a special case. Under these conditions, the firms in the industry will attempt to solve the following problem:

$$\underset{q}{Maximize}\ \Pi(q,x) \text{ subject to } q \le q°,$$

where as mentioned $q°$ is the restricted quantity. A necessary condition for solving this problem is:

(3.1b) $\Pi_q - \mu \le 0,\ q \ge 0,\ (\Pi_q - \mu)\cdot q = 0,$

where μ is the shadow value of the constraint. Now (3.1b) is formally identical to (3.1). Therefore the theory of rents as derived for optimal harvesting above applies to the suboptimal case as well. The point is that it doesn't really make any difference for the theory of economic rents how *q* is constrained as long as it is constrained.

If the harvest constraint is not binding, as in the case of open access fisheries and certain management regimes, μ will be zero[2] and therefore, by (3.1b), $\Pi_q=0$! So, in this case, rents will be zero. We state this as Result 3.

Result 3
In an open access fishery, if there are no harvest constraints, fisheries resource rents will be zero.

Note, however, that even if fisheries resource rents are zero, there may be rents associated with some other restricted inputs (or outputs). Thus, for instance there may be rents associated with limited fishing days, capital restrictions, gear size etc. Thus, there may be rents in the fishery although they are not fisheries resource rents in the above sense or that of (4). Whether such rents would be sustainable or transient is another matter.

The shape of the fisheries rents function

Given that we can use (4) for fisheries rents under any management, it is of some interest to derive the shape of the $R(q,x)$ function. Now, clearly $R_q(q,x)=D(q)\cdot(D_q(q)\cdot q/D(q)+1)$. So, the effect of increased extraction on rents is positive if the elasticy of derived demand[3] is less than unity and vice versa. By the same token rents are maximized at the level where the elasticity of demand equals unity. Moreover, if $\Pi_{qqq}\le 0$, $R(q,x)$ will be concave in *q*. Finally, $R_x(q,x)>0$ iff $\Pi_{qx}(q,x)>0$.

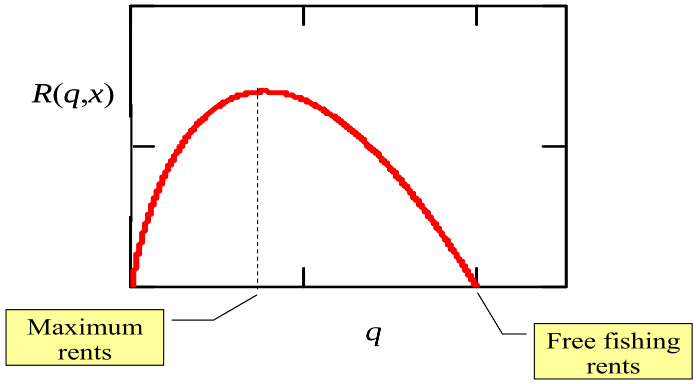
Figure 3 provides an example of a fisheries rents function for a very simple fisheries model. defined as:

$$\Pi(q,x) = p \cdot q - c \cdot \frac{q^b}{x}$$

where q and x represent the volume of harvest and biomass as before. p denotes the price of landed fish and c and b are cost parameters. For this case fisheries harvest rents are defined by the expression:

$$R(q,x) = p \cdot q - b \cdot c \cdot \frac{q^b}{x}.$$

Figure 3
Rents as a function of harvest quantity
(x=p=1, c=0.5 and b=1.1)



RELATIONSHIP BETWEEN RENTS AND PROFITS?

The key result concerning the quantitative relationship between rents and profits is that there is no such relationship. Rents can greater, less or equal to profits. We now establish this formally.

Consider any economic activity using q as a factor of production. (As previously mentioned, the process could just as easily be utility generation in which case q would be a consumption good). Let q be constrained at $\bar{q}$. Then the overall profits (or utility) is:

$$\Pi(\bar{q},\mathbf{z}) = \int_0^{\bar{q}} \Pi_q(q,\mathbf{z})dq$$

This can obviously be rewritten as

$$\Pi(\bar{q},\mathbf{z}) = \int_0^{\bar{q}} \Pi_q(q,\mathbf{z}) - \Pi_q(\bar{q},\mathbf{z})dq + R(\bar{q},\mathbf{z}),$$

where $R(\bar{q},\mathbf{z}) \equiv \Pi_q(\bar{q},\mathbf{z}) \cdot \bar{q}$, — note that $\Pi_q(\bar{q},\mathbf{z})$ is independent of q. But the integral on the RHS of this expression is simply the demanders' surplus or intra-marginal rents already discussed. Therefore, we have:

(5) $\Pi(\bar{q},\mathbf{z}) =$ demanders' surplus + rents.

Expression (5) is useful in many applications. The main point here, however, is that that irrespective of the rents, the demanders' surplus can be any sign.

An exact Taylor expansion of the profit function around $\bar{q}$ yields:

$$\Pi(0) = \Pi(\bar{q}) + \Pi_q(\bar{q}) \cdot (0-\bar{q}) + \Pi_{qq}(\hat{q}) \cdot (0-\bar{q})^2/2, \text{ some } \hat{q} \in [0,\bar{q}].$$

Rearranging we find:

(5) $\Pi(\overline{q}) = \Pi(0) - \Delta + \Pi_q(\overline{q}) \cdot \overline{q}$,

where $\Delta \equiv \Pi_{qq}(\hat{q}) \cdot \overline{q}^2 / 2$ is the quadratic term.

For a weakly concave profit function (which is really necessary for economic regularity (see e.g. Varian 1984)), $\Delta \leq 0$. Now, $\Pi(0)$ represents the profits obtained when there is no production. This equals the negative of what is usually called fixed costs. Thus, presumably $\Pi(0) \leq 0$. We immediately derive the relationship between profits and rents summarized in Table 1.

Table 1
Relationship between profits and rents

	Profit function	
Fixed costs	Linear, $\Pi_{qq} = 0$	Strictly concave, $\Pi_{qq} < 0$
Positive ($\Pi(0) < 0$)	$\Pi(q) < \Pi_q(q) \cdot q$	?
Zero ($\Pi(0) = 0$)	$\Pi(q) = \Pi_q(q) \cdot q$	$\Pi(q) > \Pi_q(q) \cdot q$

Thus we see that profits can be either grater or smaller than economic rents. In particular, in the most plausible situation — a strictly concave profit function and positive fixed costs — the relationship in indeterminate. More precisely it depends on the relative magnitudes of the fixed costs and the curvature of the profits function represented by Δ. Let Φ represent this difference, i.e. $\Phi = \Pi(0) - \Delta$. Then, if Φ>0 then $\Pi(q) > \Pi_q(q) \cdot q$ and vice versa.

The relationship between variable profits, i.e. $\Pi(q) - \Pi(0)$, and rents is much more straight-forward. Inspection of equation (5) shows that variable profit are always greater or equal to rents provided the profit function is at lest weakly concave. More formally

(6) $\Pi(q) - \Pi(0) \geq \Pi_q(q) \cdot q$

The equality applies when the profit function is linear, i.e. Δ=0.

RENT LOSS IN THE GLOBAL FISHER: A NUMERICAL EXAMPLE

To illustrate how rents and rent loss may be calculated in practical cases, we employ a very simple stylized model of the global fishery (i.e. the ocean capture fishery).

The harvesting function:

$Y(e,x) = \varepsilon \cdot e \cdot x$,

where e represents fishing effort and x biomass. ε is often referred to as the catchability coefficient.

Biomass growth:

$$\dot{x} = G(x) - Y(e,x) = a \cdot x - b \cdot x^2 - \varepsilon \cdot e \cdot x,$$

So, natural biomass growth is described by the quadratic function $G(x) = a \cdot x - b \cdot x^2$, where a and b are biological parameters. Note that in this equation a represents the intrinsic growth rate and a/b the virgin stock equilibrium.

Harvesting costs:

$$C(e) = c \cdot e^f + fk$$

where c and f are cost coefficients. The coefficient f is the elasticity of variable costs with respect to effort. For concavity of the profit function, $f>1$. fk represents fixed costs.

The above model contains seven parameters (a, b, ε, p, c, f, fk). To obtain estimates of these parameters, we make use of the following stylized description of the global fishery. Note that the stylized description is not supposed to be accurate. The main purpose of this section is to illustrate how fisheries rents and loss of fisheries rents can be calculated once a description of the fishery is available. It is straight forward to redo the calculations for an improved description of the fishery.

Table 1
Stylized description of the global ocean fishery

A1	Maximum sustainable yield (MSY)	100 million metric tonnes/year
A2	Maximum biomass (utilized species)	400 million metric tonnes
A3	Current catch per unit effort (cpue)	6.0 metric tonnes/GRT
A4	Average landings price per metric tonne, p	1 USD/kg
A5	Elasticity of variable costs, f	1.1
A6	The global fishery is currently:	Close to sustainability
A7	Current competitive profits (excl. subsidies)	-5 b. USD/year
A8	Global fishery	Close to economic equilibrium
A9	Global fish harvest is currently	85 m. metric tonnes

In terms of our simple fisheries model, these assumptions imply the following values for the parameters:

Table 2
Model parameters

Parameters	**Values**	**Units**
a	1.0	Time^{-1}
b	0.0025	$(\text{Metric tonnes} \cdot \text{time})^{-1}$
ε	0.05	GRT^{-1}
p	1	USD/kg.
c	4.3	USD/GRT
f	1.1	No units
fk	13	Billion USD/year

Substituting the parameters in Table 2 into the fisheries model, we can derive the sustainable fisheries model as illustrated in Figure 4: As drawn in Figure 4, the profit maximizing sustainable fishery[4] implies much less fishing effort, similar harvest and higher profits than the current fishery. Biomass is also much higher in the optimal fishery. Calculating these values as well as rents yields the following table.

Figure 4
The global sustainable fisheries model

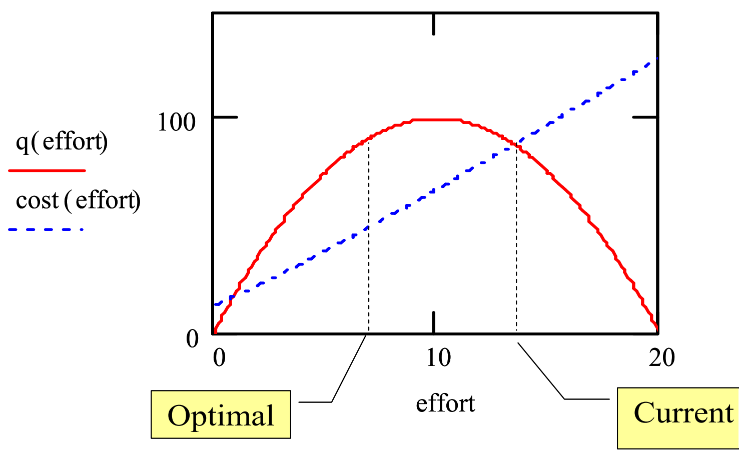


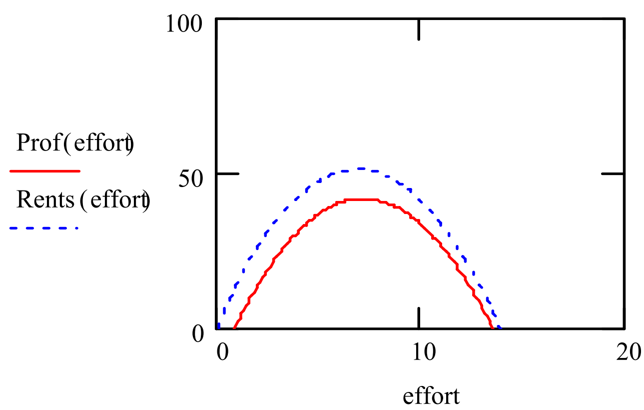
Table 3
Sustainable global fishery: Current and profit maximizing outcomes

	Current	**Optimal (profit maximization)**	**Difference (optimal –current)**
Fishing effort	13.9 m. GRT	7.3 m. GRT	-6.6 m. GRT
Harvest	85 m. mt	93 m. mt.	+8 m. mt.
Biomass	123 m. mt	254 m. mt.	+131 m.mt.
Profits	-5.3 b. USD	41.6. b.USD	46.9 b.USD
Rents	0 b. USD	50.8 b. USD	50.8 b. USD

According to the results listed in Table 3, the rent loss in the global fishery is about 50 billion USD annually. The profit loss is slightly less or about 47 b. USD.

The relationship between rents and profits at varying levels of fishing effort is illustrated in Figure 5. Note that rents are higher than profits at all levels of fishing effort. The main reason is we have assumed very substantial fixed costs in the global fishery while the degree of concavity of the profit function is comparatively small. As a result, fixed costs overwhelm the concavity effects in the sense discussed in the section of profits and rents above. Consequently, rents exceed profits.

Figure 5
Equilibrium rent and profit functions: Graphs



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ENDNOTES

1 Since the factor is by assumption in fixed supply, there can be no opportunity costs associated with its supply.

2 This follows from the Kuhn-Tucker theorem.

3 Defined as $-(D_q(q)\cdot q/D(q))^{-1}$.

4 This is calculated assuming the rate of discount to be zero. A positive rate of discount implies a slightly higher fishing effort and harvest and slightly lower biomass, profits and rents. For any reasonable rate of discount (i.e. less than 10%), the difference is very small, however.